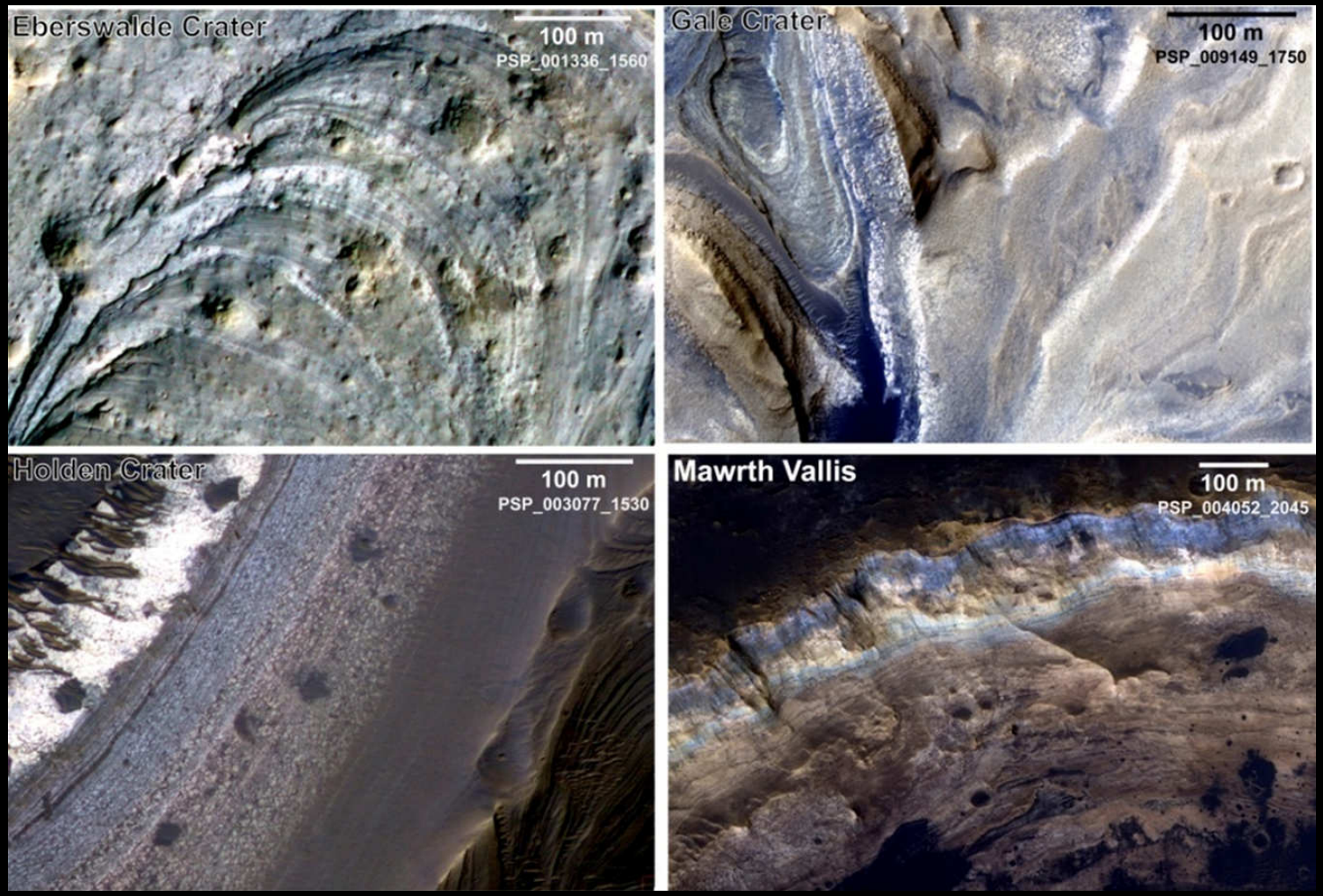
MSL Landing Site Selection Update:

Mars Landing Site Selection Activities



John Grant,
(Smithsonian Institution)

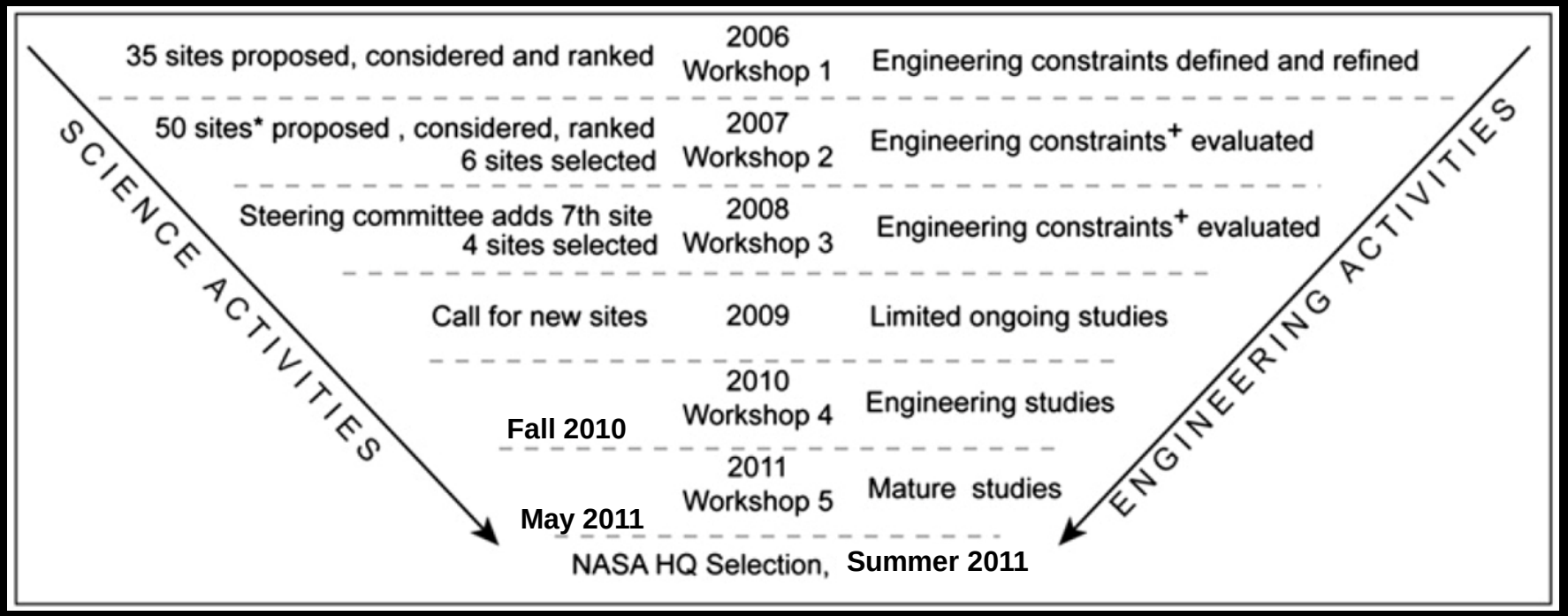
Matt Golombek
(Jet Propulsion Laboratory,
California Institute of Technology)

MSL Project
J. Grotzinger, M. Watkins, A. Vasavada

MSL Landing Site Selection Activities:

Mars Landing Site Selection Activities

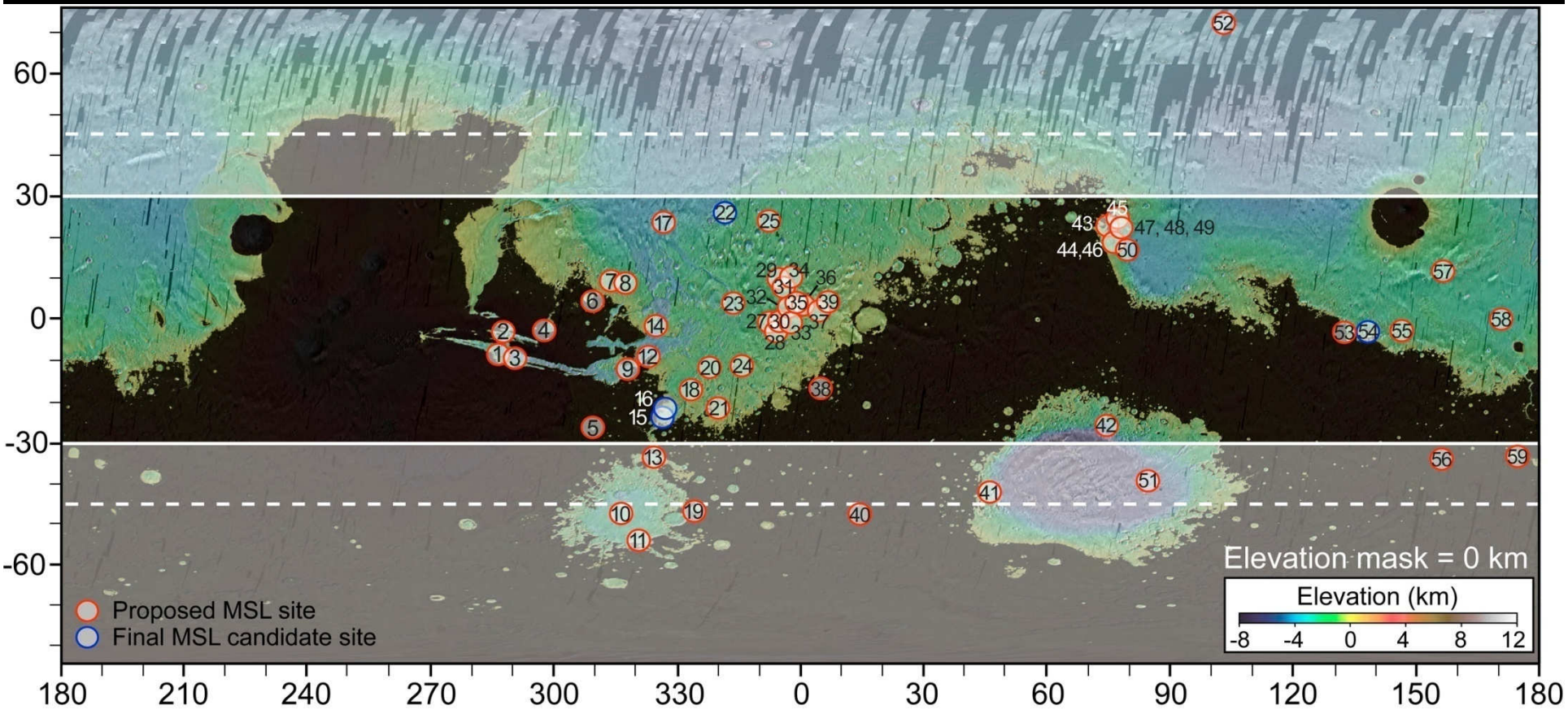
A Relatively Long and Occasionally Strange Trip…



…But Remarkably Comprehensive and Scientifically Rich

Proposed MSL landing sites:

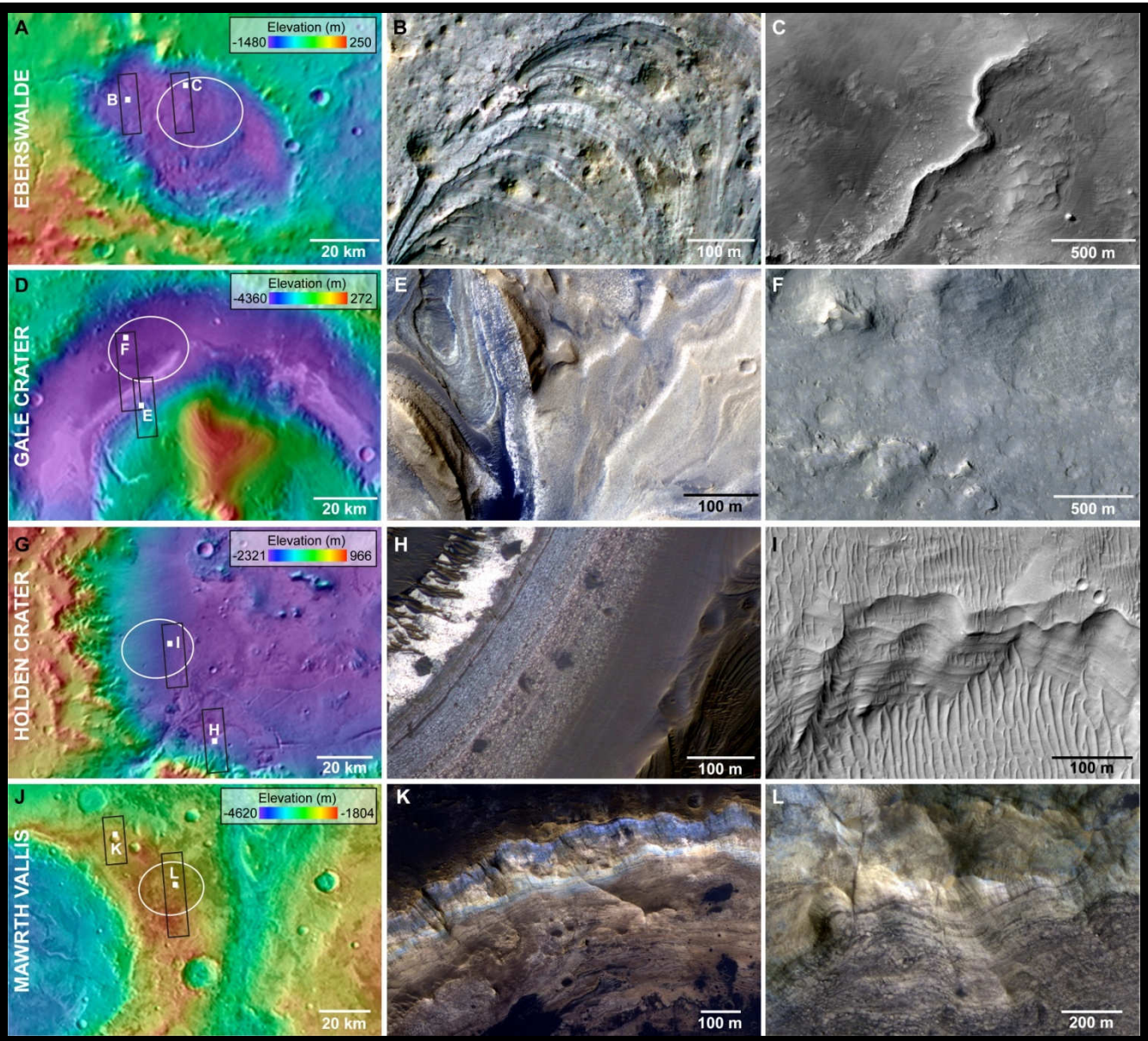
Mars Landing Site Selection Activities



Shaded areas are above +30°N, below -30°S, and above 0 km in elevation

Overview of the Final Four Candidate Landing Sites:

Mars Landing Site Selection Activities



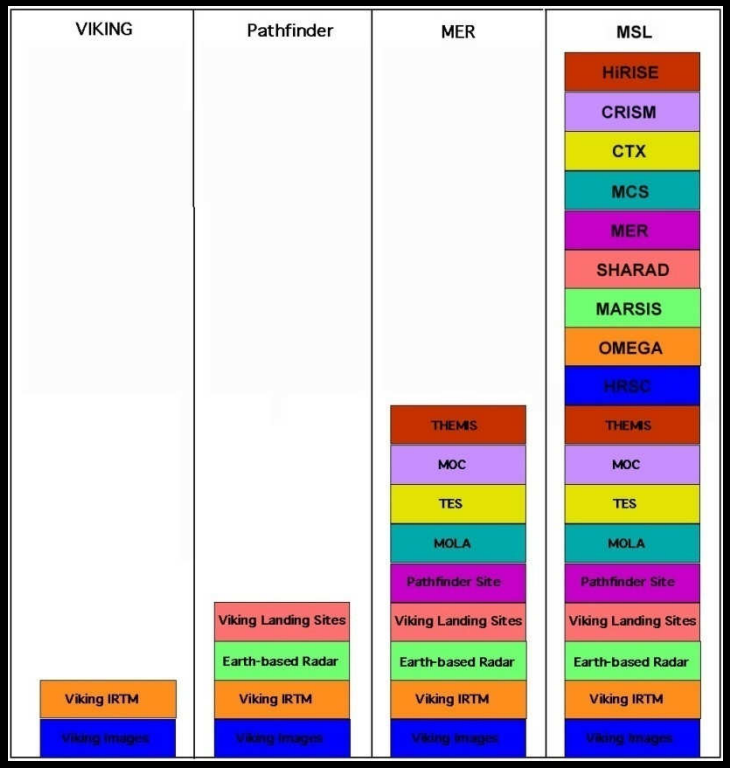
Each of the final four sites represents an exciting science target

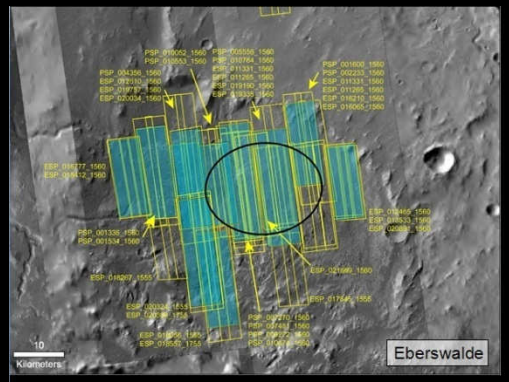
Evaluating Candidate MSL Landing Sites:

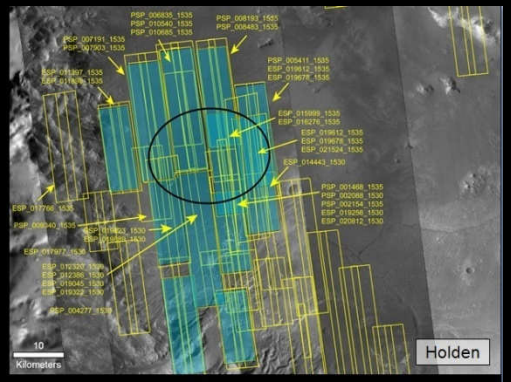
Mars Landing Site Selection Activities

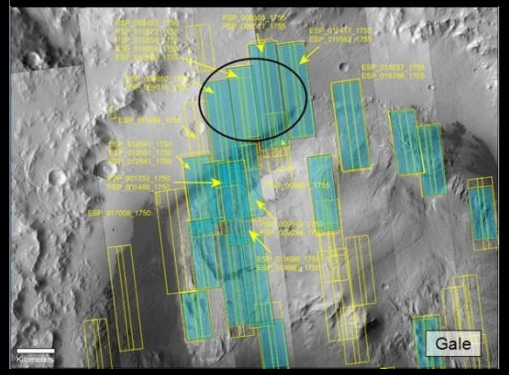
Current orbital assets have set the new standard for data required for identifying and qualifying new Mars landing sites

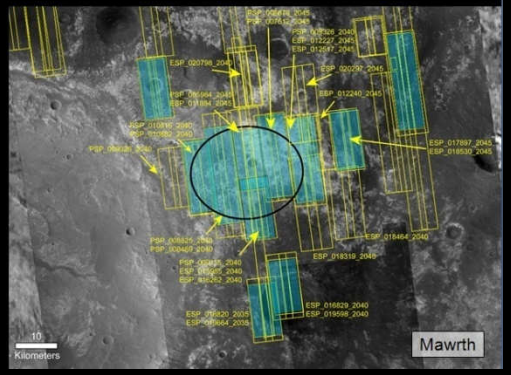
An incredible effort by instrument teams has gone into obtaining high quality data used to evaluate candidate sites











More than 200 MRO Observations of Candidate Landing Sites to Date!

Records of the Process:

Mars Landing Site Selection Activities

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The science process for selecting the landing site for the 2011 Mars Science Laboratory

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ABSTRACT

The process of identifying the landing site for NASA's 2011 Mars Science Laboratory (MSL) began in 2005 by defining science objectives, related to evaluating the potential habitability of a location on Mars, and engineering parameters, such as elevation, latitude, winds, and rock abundance, to determine acceptable surface and atmospheric characteristics. Nearly 60 candidate sites were considered at a series of open workshops in the years leading up to the launch. During that period, iteration between evolving engineering constraints and the relative science potential of candidate sites led to consensus on four final sites. The final site will be selected in the Spring of 2011 by NASA's Associate Administrator for the Science Mission Directorate. This paper serves as a record of landing site selection activities related primarily to science, an inventory of the number and variety of sites proposed, and a summary of the science potential of the highest ranking sites.

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1. Introduction

The selection of the landing site for the National Aeronautics and Space Administration (NASA) 2011 Mars Science Laboratory (MSL) rover plays a crucial role in the success of the mission. Although this paper emphasizes science activities related to selection of the MSL landing site, a myriad of orbital datasets from multiple missions were utilized to characterize each potential landing site from a science and engineering standpoint. The objective of all landing site activities is to maximize the chance of landing safely with access to high-priority science targets.

Science and engineering characterization of the landing sites emphasizes data from the Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM, see Murchie et al., 2007), High Resolution Imaging Science Experiment (HiRISE, see McEwen et al., 2007), and Context Camera (CTX, see Malin et al., 2007) instruments, Mars Odyssey Thermal Emission Imaging System (THEMIS, see Christensen et al., 2004) instrument, Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC, see Malin et al., 1992), Mars Observer Laser Altimeter (MOLA, see Zuber et al., 1992), and the Mars Express Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA, Bibring et al., 2004) spectrometer and High Resolution Stereo Camera (HRSC, Jaumann et al., 2007).

The safe delivery of MSL to Mars' surface also depends upon the characterization of the atmosphere through which the spacecraft flies. The MSL spacecraft's entry, descent, and landing system involve a guided entry, parachute deployment, and a rocket-powered terminal descent to the surface. A team of atmospheric scientists has been advising the mission and providing model-based predictions of atmospheric density, winds, and the probabilities and effects of dust storms at the MSL arrival season. These atmospheric assessments will be described in a separate publication; here we focus on the terrain.

The inferred geologic setting of the site must lend confidence that the rocks and outcrops suitable for achieving core science objectives (Grotzinger, 2009; Table 1) are present and accessible. While both science and engineering aspects of landing site selection are critical to mission success, the engineering constraints trump science because there is no science return unless the mission lands safely on the surface of Mars. This paper provides a summary of the landing site selection process for the MSL rover with emphasis on the science activities related to selecting the optimal site.

Due to the diverse nature of the Martian surface and quantity of data available, the Mars science community was enlisted to assist in the site selection process via a series of workshops that were open to the science community and public. The process is modeled after the successful Mars Exploration Rover (MER) site selection process

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All Science and Characterization Presentations made at all workshops and all decision letters are preserved at:
http://marsoweb.nas.nasa.gov/landingsites/

http://webgis.wr.usgs.gov/msl/

A link to published papers related to the final four candidate sites:

msl.gps.caltech.edu

Summary Paper in Planetary and Space Science

Fifth MSL Landing Site Workshop in May, 2011:

Discussion focused on outstanding questions and science targets for each of the sites. Had in depth, uniform discussion of key points related to all four sites.

All sites deemed "safe" for landing and traversability, so…

Emphasis was squarely on the science of the sites

All four candidate sites are very highly rated by Science

Did not vote on the sites at this Workshop.

All agreed that each of the sites represented a fantastic target for exploration by MSL

Began development of "testable hypotheses" for each site.

Deliverable was "Quad Charts" that detail the relative merits and weaknesses of each site relative to MSL objectives.

Site Characterization:

Best Imaged, Best Characterized Landing Sites in Mars Exploration History

Extensive Acquisition & Analysis Orbiter Data

- Create Data Products that Address Engineering Constraints
- CDP Supports Generation of Data Products
- HiRISE DTMs & Photoclinometry, Rock Maps, Thermal Inertia, MOLA Slopes, CTX DTMs, Radar Analysis

Support Engineering Landing Simulations & Safety Analysis

- Engineering Constraints on Landing Sites
  - Latitude, Elevation, Ellipse Size, Slopes (many scales),
  - Rocks, Radar Reflectivity, Load Bearing (thermal inertia & albedo)

Support Traversabilty Analysis

- Example Traverse Timelines

Consideration of all data sets to date indicates that all four sites are "safe" for landing and traversing

Eberswalde Crater Site

23.9S, 327E

Overarching Hypothesis:

- Eberswalde crater stratigraphy, geomorphology, and mineralogy record the evolution of a crater lake, the history of hydrologic and climatic changes resulting in the formation of fluvial-deltaic systems, and a sedimentary depositional environment that might have been favorable to the preservation of organic materials and/or other kinds of biosignatures.

Possible Cons of Site:

•Relatively limited variety and modeled abundance of phyllosilicate minerals known to preserve organics detected from orbit.

•Science in landing ellipse is secondary to that outside of the ellipse.

Specific Pros of Site:

Setting -

•Eberswalde shows excellent preservation of a fluvial-deltaic system emplaced into a standing body of water that integrates sedimentary material from a broad source region. Additional, smaller fluvial-deltaic systems and possible lacustrine deposits are also present.

•The landing site provides the opportunity to reconstruct quantitatively the sedimentary, hydrologic, and climate conditions during deposition. Specific formation models allow prediction of locations to target for exploration with MSL. Bottom set beds from each lobe of the delta can be defined and provide targets in which to seek organics.

•Evidence for episodic channel-meandering migration is recorded in the delta and associated estimates of discharge suggest its deposition extended for several hundred thousand years or more based on terrestrial analogs.

Diversity -

•In addition to fluvio-lacustrine deposits (e.g., sinuous ridges), Holden crater ejecta and possible megabreccia related to the Eberswalde impact event occur. Some megabreccia may express veins related to hydrothermal activity. The materials in the ellipse and delta include clay minerals whose distribution is associated with different outcrop characteristics.

Preservation -

•Orbital detection of clay minerals near the bottom of the delta front, maybe in bottom set deposits, define a well-defined target for exploration. There are also potential lake deposits within the landing ellipse that offer exploration targets. On Earth, such deposits can concentrate and preserve organics and evidence for habitability and life.

Exploration Targets –

•Well-defined fluvial-deltaic-lacustrine and megabreccia targets coupled with mineralogical diversity within and outside of the ellipse defines a short and long term exploration strategy. Lacustrine sediments likely exposed in and near the ellipse and distribution is becoming well-mapped. Distribution of targets make exploration of the site a mix of land on and go to.

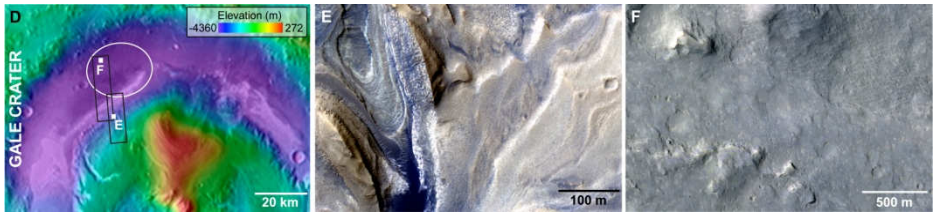
Remaining Uncertainties:

• Little evidence for shorelines corresponding to the elevation of the delta surface and the spillway to the eastern basin, though some aspects of the system (including the poorly defined shorelines) suggest it may have been ice-covered (though no deformation of delta as might be expected if it was). Predictions made enable this to be evaluated in situ.

• Delta emplacement might be consistent with delivery of water and sediment shortly after the Holden impact; this cannot be ruled out in advance of landing, but tests are proposed to resolve in situ. Sediment contributions to the delta from Holden ejecta are uncertain though mapping of tributaries and characteristics of incision will help resolve in advance of landing.

• Delta is no older than Early Hesperian and some investigators believe it may have been deposited as late as the Early Amazonian, but there is no consensus whether a post-Noachian age is of a concern for preserving organics or for preserving evidence for past habitability or life on Mars.

Gale Crater Site



4.5S, 137.4E

Overarching Hypothesis:

- Strata within the 5 km thick mound of layered sediments within Gale crater record a sequence of aqueous habitable environments over an extended period. These strata contain multiple hydrous minerals (sulfates, phyllosilicates) that indicate varying aqueous environmental conditions.

Possible Cons of Site:

• The original extent and timing of processes responsible for the present mound morphology needs better definition and the regional and global stratigraphic context of the mound is not firmly established and it is unlikely that all depositional aspects of the mound will be understood in advance of landing.
• Science in landing ellipse on and near an alluvial fan is secondary to that outside of the ellipse and observations within the ellipse may be encumbered by dust.

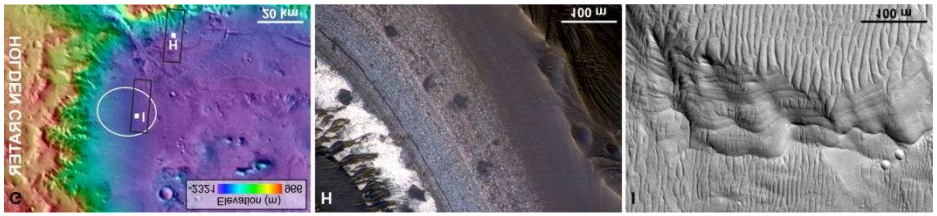
Specific Pros of Site:

Setting -
•Diverse stratigraphy in a 5 km mound within a 5 km deep Late Noachian crater. Stratigraphy includes well-defined beds of hydrated minerals and the lower mound includes contributions by fluvial processes and likely reflects deposition during changing and possibly global scale wetter-to-drier environmental conditions.
•Alluvial materials and inverted channels in the ellipse record hydrologic conditions when they were emplaced and provide the opportunity to sample materials weathered and eroded from the crater walls.
Diversity -
•Multiple mineralogical and stratigraphic units within the 5 km thick mound sequence with alternating inter-bedded phyllosilicate and sulfate bearing beds in the lower mound. Stratigraphy comprising the mound is continuous over many km and well characterized in places.
•Alluvium in the landing ellipse enables sampling crater rim materials that may record environmental conditions during their emplacement and from before the formation of the north-south dichotomy on Mars.
Preservation –
•The phyllosilicate-bearing units in the lower mound and moat include smectites that would help preserve organics if present. Biosignatures may be best preserved in the sulfate bearing strata in the mound.
Exploration Targets –
•The specific distribution of science targets within and outside of the ellipse is well defined. Preserved organics could occur in a high thermal inertia unit in fan in ellipse, in clay rich layers that may not have sulfates, and in the sulfates.

Remaining Uncertainties:

• Although several testable models for mound formation exist, uncertainty remains about the depositional setting for much of the stratigraphy despite a better understanding of the constituent mineralogy. Nevertheless, bed continuity and morphology implies origin of lower section involved deposition onto a wet surface or into standing water and there is evidence for fluvial redistribution of mound materials.
•The source of water associated with deposition remains uncertain, but if sediments were deposited in a lake, the relative paucity of associated valleys suggests groundwater as opposed to meteoric sources.
• The source of the lower mound sediments is unknown but likely from outside of the crater and it is uncertain whether the mound is part of a larger deposit (though it is morphologically similar to deposits seen elsewhere on Mars). Valleys breaching the rim at a stratigraphic level now lost to erosion may have contributed fill to the crater and/or in lake.
• Crater statistics suggest Gale is Late Noachian, whereas floor deposits onlapping the lower mound and including the fan in ellipse are interpreted to be Early Hesperian, thereby bracketing the age of the lower mound. Age of upper mound and total time recorded in the mound is uncertain.
•Preservation potential of organics in the sulfate units may be compromised by the known presence of iron oxides.

Holden Crater Site



26S, 325E

Overarching Hypothesis:

- Holden crater preserves evidence of a closed fluvial-lacustrine system that provides the opportunity to apply a geomorphic systems approach to evaluating and preserving evidence for a sustained, habitable environment.

Specific Cons of Site:

• Origin of stratified light-toned materials as lacustrine versus alternate depositional processes remains uncertain, but in situ evaluation of bedding character and chemistry is likely to distinguish origin.
• Relatively limited variety of phyllosilicate minerals known to preserve organics detected from orbit.

Specific Pros of Site:

Setting -
•The bajada in the ellipse and light-toned layered materials comprise one of the largest and best preserved alluvial systems on Mars. The diverse and potentially weathered sediments likely record the environmental conditions responsible for their formation during the Hesperian perhaps into the Early Amazonian. This sequence is underlain by the light-toned layered deposits and overlying Uzboi flood deposits and enable the age of the target deposits to be related to global stratigraphy.
•Collectively, additional diverse and widespread megabreccias in and outside the ellipse and alluvial materials in the ellipse suggests sampling of rocks ranging in age from early crustal Noachian to perhaps into the Hesperian or even Early Amazonian.
Diversity -
•Diversity is represented by fan sediments, phyllosilicate-bearing light toned layered deposits, Uzboi flood deposits, and mega-breccias in the crater walls/floor.
•The mineralogical diversity in the light-toned layered deposits and crater walls/floor include both altered and primary compositions.
Preservation -
•Strata comprising the light-toned layered materials may be the equivalent of bottom set beds emplaced in a lacustrine setting, which might preserve organics for interrogation by the MSL.
Exploration Targets –
•Well-defined exploration targets exist within and outside the landing ellipse. Targets within the ellipse offer access to all major units for interrogation, though thicker sections of the light-toned layered materials and megabreccias occur farther to the south. Putative bottomset beds provide a target for evaluating any preserved organics

Remaining Uncertainties:

• There are no shorelines or stratal geometries and limited evidence for other properties associated with the light-toned layered deposits and fans that can be used to more confidently define their origin and genetic relationships.
• Diverse megabreccia occurrences within the ellipse, walls, and rims may include evidence that they supported an impact-induced hydrothermal system.
• Light-toned layers high on the west wall of Holden may relate to older beds excavated from the pre-existing Holden basin.
• Age of light-toned layered deposits and adjacent alluvial fan surfaces are no older than Early Hesperian and fans may be as young as Early Amazonian, though there is no consensus whether this is an issue for habitability and evaluating conditions for life.

Mawrth Vallis Site

24N, 341E

Overarching Hypothesis:

- Mawrth Vallis records geologic processes during early Martian history, when aqueous phyllosilicate-forming processes were pervasive and persistent. This site provides the opportunity to understand the potential for early habitability on the planet and may be representative of global conditions on Mars.

Possible Cons of Site:

• There is no consensus on the depositional setting or the mechanisms for concentrating or preserving organics and it is unlikely that the depositional setting will be further refined prior to landing and in situ evaluation.
•Although textural and chemical characterization of the units using the MSL payload may distinguish between models for emplacement history, there is not a consensus that such an approach will be successful.

Specific Pros of Site:

Setting -
•Exposes the oldest preserved rocks of the four candidate sites and provides an opportunity to explore Noachian crust to seek and investigate information about the processes active on early Mars.
•The relative ages of exposed rocks are well constrained and suggests they are among the oldest preserved on Mars and might be from a period not recorded in the rock record on Earth.
•Hydrated minerals are present and modeled to contribute several tens of percent by volume to the rocks (most of any of the sites) that formed in aqueous environments. The section within and near the landing ellipse appears to be mineralogically representative of other Noachian crustal sections in Arabia Terra, thus allowing an understanding of what possibly were widespread processes on early Mars. Capping mesa-forming materials appear unaltered and may record changing conditions during the Hesperian and younger times.
Diversity –
•The ellipse and go to outcrops encompass a diverse, complex mineralogical and rock sequence that includes many of the hydrated minerals found on Mars (multiple phyllosilicates and sulfates) whose formation records varying aqueous environmental conditions and any changes in surface aqueous alteration environments. Rocks were likely emplaced by multiple geologic mechanisms that probably included diagenetic (e.g., for Al-phyllosilicates), impact, fluvial, and/or pedogenic processes, and remain in situ.
Preservation -
•Several locations in close proximity and within the ellipse may allow interrogation of a variety of rocks to help define the early period of time when water was present and determine whether the environment was habitable. The phyllosilicate-bearing units include smectites, suggesting they are well preserved and may contain/help preserve organics.
Exploration Targets –
•A good list of prioritized targets within the ellipse has been identified and targets outside the ellipse, including sulfates, are also well-defined. Both the Mg/Fe and Al- bearing phyllosilicate units need to be interrogated to assess the nature and distribution of any organics.

Remaining Uncertainties:

• The depositional setting(s) associated with emplacement of the rocks and mineralogic units at Mawrth remains uncertain, is unlikely to be resolved using existing orbital data sets, but may be resolved in situ.
• It is uncertain if the observed alteration record (i.e., represented by the Al-phyllosilicates) extends to the primary Fe/Mg smectite deposit and its potential organic record.
• It remains uncertain whether Oyama crater ejecta persists or which unit it might correspond to, though Al-phyllosilicates likely post-date Oyama.
•The amount, source, and duration of interaction with water in development of the units remains uncertain.

Future Schedule:

Project Recommendation
Independent Peer Review
NASA Selection of Landing Site – early Summer 2011

MSL Launch late 2011